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THE ANORTHOSITES OF BENGAL

BY

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CALCUTTA UNIVERSITY PRESS
1936

PRINTED BY BHUPENDRALAL BANERJEE
AT THE CALCUTTA UNIVERSITY PRESS, SENATE HOUSE, CALCUTTA.

Reg. No. 14 C. U.—July, [illegible]

CONTENTS

THE ANORTHOSITES OF BENGAL

ABSTRACT

The anorthosite rocks of Bengal occur as an elongated sheetlike mass within the Archaean rocks, along the northern part of the district of Bankura, and extend into the adjoining district of Manbhum. There are associated granite and norite dikes and contemporaneous veins. The structural relation, microscopic characters and chemical composition of all the three types and other varieties are fully indicated and discussed in relation to their bearing on the mode of origin of the anorthosite rocks in the light of researches done in recent times in America. Bowen's ideas as modified by Balk seem to offer a satisfactory explanation of most of the observed phenomena.

I. INTRODUCTION

Ever since Bowen wrote his classical paper on the "Problem of the Anorthosites" (Bowen, 1917), there has been a great deal of controversy on the question of their origin and there is even now a considerable difference of opinion among petrologists on some of the major problems. It was thought that a careful record of field observation and laboratory work on a hithertofore little-known body of anorthosite might throw some light on the problem. A detailed study of the anorthosites of Bengal was therefore undertaken some years ago at the suggestion of the late Prof. Dasgupta. The purpose of the present paper is to record the observed facts and to consider the applicability of the several theories proposed by different petrologists to the interesting problem of the origin of anorthositic rocks.

II. PREVIOUS WORKERS

The first systematic geological account of this area was given by Oldham in 1859 before the name "Anorthosite" came into use in geological literature.*† Oldham recognised the feldspathic nature of the rocks in the eastern part of the area under description and the greater

* Mem. Geo. Surv. of India, Vol. I, p. 253.

† The name Anorthosite was first proposed by Sterry Hunt in 1863 in his Geology of Canada.

liability to weathering of the more feldspathic varieties. The massive anorthosites of Ramchunderpur were described as a curious granitite "composed of quartz and felspar with imbedded crystals of a second felspar of a leaden grey colour." The occurrence of trap dikes and granite veins in these rocks were also noted by him.

The next account of the geology of this area is found in Ball's Geology of Manbhum and Singhbhum (Ball, 1881). The rocks described by him as 'rusty-looking quartzite' and 'felspar porphyry' are probably anorthosites. According to Ball these rocks 'are traceable for a distance of about 7 miles, after which they die out' and are followed by traplike hornblendic rocks. The latter seemed either to be greenstones and diorites or hornblendic schists.

Sir Thomas Holland first identified these anorthosites and norites near the south border of the Raniganj coalfield (Holland, 1900). I take the liberty of quoting in full the important observations made by Sir Thomas Holland :—

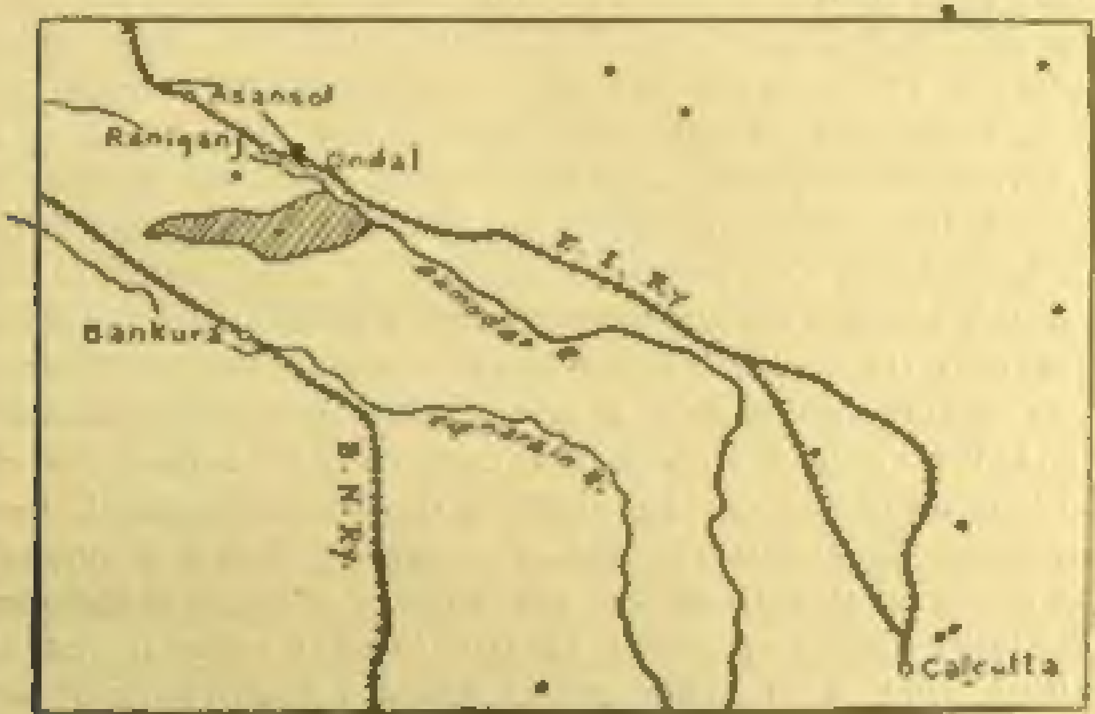
> "The Norites are fine-grained and granulitic, sometimes foliated and sometimes showing an occasional garnet. The labradorite rocks are very variable in the size of their crystals, the ferromagnesian constituents which occur in comparatively small quantities, include an occasional olivine with well defined reaction rims."

The present author undertook a detailed study of these rocks in 1928 and published a short preliminary note on them in 1929 (Chatterjee, 1929). Since then he has been engaged in a systematic mapping of the different scattered outcrops. During the last few years there has been a good deal of intensive study of similar rocks, especially in America, and the writer has taken every opportunity to check all ideas and views of the petrologists engaged in these studies against his own personal observations in the field and in the laboratory.

III. Area and Boundaries

The prevailing idea was that these anorthosite rocks are found only locally near Raniganj, but an attempt to fix its boundaries revealed its greater extension. The rocks were traced for some 18

miles towards the west, and dikes of anorthosite were found even at a distance of 20 miles from Holland's original locality. The main outcrop is comparatively narrow, the width being only five to six miles. It extends from the western bank of the Damodar river in the east, to the neighbourhood of the B. N. railway line to Adra from Kharagpur. The greater part of this narrow zone lies in the district of Bankura in the province of Bengal, but the western extremity lies in the district of Manbhum in the province of Bihar. The entire region lies between lat. 23° 33′ N and lat. 23° 27′ N and between longitude 87° 15′ E to 86° 47′ E. During the present mapping the writer used the following topographical sheets of the Survey of India, all on the scale of 1″ = 1 mile: 73 $\frac{M}{2}$, $\frac{M}{3}$ and 73 $\frac{I}{14}$, $\frac{I}{15}$. The following sketch map will give a clear idea of the location of the area:



(Scale 1″ = 64 miles.)

IV. Physical Features, Drainage, Vegetation, etc.

In physiographical features the region marks the transition from the rolling flat alluvial plains of Bengal to the rugged uplands of the Chota Nagpur plateau. The northern and the western parts of the

region are therefore hilly and the surface there is undulating, while in the south and east it merges into the level plains of deltaic Bengal. Exposures of rocks are few and far between, and the geology of the country is completely hidden by the alluvium in most places. The geologist has to confine his attention mostly to the stream sections, but here and there rough hummocky masses of rocks raise their heads above the general surface of the country. North of the region occupied by the anorthosite, the country rocks such as gneiss, schists and sandstones form prominent hills ; and similarly in the south the isolated hill of Susunia made of Cuddapah sandstone forms a prominent feature of the landscape.

The central part of the tract is at a slightly higher elevation in many places and forms the chief water-parting of the country. It runs approximately from west-north-west to east-south-east, and gradually sinks into the eastern plain, near the Damodar. North of this axis, the drainage of the country finds its way into the Damodar basin through the several short but rapid hill streams which run from south-west to north-east, such as the Gaigbata Jhor and Chouphari Jhor. To the south the Dangra and the Gandheswari run towards the south-east to meet the Dwarakeswar or the Dhalkisor which here forms the principal stream. Further south in lower Bengal, this becomes the magnificent river Rupnarain which joins the Ganges near its mouth. These streams nearly dry up during the summer, leaving behind only a few shallow pools of stagnant water here and there or flow with a slow current, but during the rainy season they are liable to sudden floods and are converted into torrential streams. The climate is bracing in winter, but it is one of the hottest places in Bengal during the summer. Much of the country was originally covered by forests of Sal (*Shorea robusta*) but these have been denuded in many places either for agricultural or for timber-cutting operations. In the rocky upland areas wherever the Sal forests have been destroyed, the vegetation now consists of small bushes of Palash (*Butea frondosa*). In fact, the latter now forms the most characteristic and ubiquitous vegetation of the district. Associated with this are Arjun (*Terminalia arjuna*), Kend or ebony (*Diospyros melanoxylon*) and Bat (*Ficus bengalensis*). There are broad extensive upland tracts whose stony soils support a scanty

vegetation of poor grass. In summer the country presents a dry, desolate aspect with its treeless undulating plains, but with the onset of the rains the whole countryside is covered with a mantle of fresh green verdure. Denudation under tropical conditions has produced the characteristic red soils in all the areas characterised by gneissic rocks, but the soil derived from the anorthosite and white feldspathic gneiss and granite consists of alluvium, rich in calcareous concretions (*ghooting*). These are collected in many places as a raw material for lime. It is said that the soil is frequently replenished with this material, as people have been collecting this year after year.

V. Field Relations

The different types of rocks found in the area studied may be put under two groups, namely, the anorthosites together with rocks syngenetic with them and the country rocks. A third group may be made to include the younger intrusive dikes, which cut all the older formations. The intrusive rocks belonging to the anorthosite series may be classified under the following heads:—

(1) Labradorite rocks—White variety of anorthosite.
(2) Anorthosite—Dark variety.
(3) Anorthosite-gabbros.
(4) Granulitic gabbros.
(5) Granites Granodiorites and Grano-anorthosite.
(6) Pegmatites.

The country rocks consist of Dharwars such as hornblende gneiss, sillimanite-biotite schists and gneisses, and intrusive gneisses such as the Bengal gneiss (Chota Nagpur granite gneiss), pyroxene gneiss and quartzo-feldspathic gneisses. These occupy by far the larger area.

Labradorite rocks.

The distinction of labradorite rocks from the anorthosite put under the second group, is based on certain well-marked macroscopic and microscopic differences between the two groups. The labradorite rocks are made up of almost pure plagioclase with a small quantity of dark minerals. The feldspars are white and are not so much schillerised as those of the second group. Occasionally they occur as phenocrysts. In hand specimens the rocks might easily be mistaken for crystalline

limestone, but the characteristic decomposition into whitish clay at once shows the true nature of the rock. These labradorite rocks (white anorthosites) are more common than the dark-coloured anorthosites and are found throughout the area, particularly along the northern strip, and occupy the entire outcrop in the west. The darker varieties occur in the south and east. They are more resistant to weathering and form large roundish and irregular blocks and hummocky masses.* (See plate 1, fig. 1.) The white varieties are more liable to decomposition and give rise to masses of white clay. In the low grounds and streams the exposed surfaces are always kaolinised but on well-drained uplands large irregular blocks of fresh rock are often found. Generally speaking the rocks show a feeble development of banding, but here and there in certain zones, the rocks show well-marked schistosity and effects of powerful shearing stress. It may be noted here that microscopic sections of these schistose and sheared varieties show that the rocks are not really anorthosites but are of more acid type. In fact they may be regarded as granodiorites. Variations are often found in the field. The darker facies is scattered widely over the entire region. Here the feldspathic constituents remain as they are, but the dark colour is due to a greater percentage of the femic constituents. These increase in quantity and often segregate together to form dark, irregular, schlieren in the white rocks. In some places the white rock is intimately penetrated by dark sub-parallel bands and the resulting rock looks like a banded gabbro. Schlieren are quite common in the neighbourhood of these bands and the percentage of the femic constituents in the white rocks also increases near these bands. Besides these dark bands there are often dikes of granulitic gabbros and norites. In some places these form large lenticular masses and being more resistant than the labradorite rock stand out as hillocks. These are quite numerous in the region south of Saltora (lat. 23° 31', long. 86° 56').

Dark varieties of Anorthosites.

The passage of the white pure plagioclase anorthosite to the dark-coloured varieties is rather sudden without any marked transition. It must not be understood, however, that there is a marked discontinuity (except in one case where the dark variety has intruded into the white

ones), but rather there is a sudden passage in the same outcrop from the white to the dark variety. As has been said before the dark colour of the rocks is due to the schillerisation of the feldspars and pyroxenes and the presence of a greater quantity of the femic minerals. On account of the dull grey colour of the schillerised feldspars, there is a superficial resemblance to the intermediate charnockites. They occur as round masses with a characteristic pitted appearance. This is due to the removal of the femic minerals such as biotite, pyroxene and garnet by weathering from the exposed surfaces. Even the most cursory observation indicates that the rock is variable in its texture and coarseness of grain. Every gradation is found from a uniformly fine-grained variety to a coarsely crystalline variety. But the more general type is a porphyritic rock in which large individuals of dark labradorite occur in a finely granulated mass of the same feldspar. Occasionally these phenocrystic feldspars assume unusually large dimensions. In one case a crystal measured 6½" × 3½" and in another 13" × 5". Closer inspection reveals that the feldspar phenocrysts have more or less a parallel arrangement. This feature has been noted also in the case of the white anorthosite wherever fresh surfaces are found. The prevalent parallelism of the large feldspars is characteristic of the anorthosite body as a whole. This may seem at first sight to be the result of dynamic metamorphism, but as these rocks do not show any schistosity or foliation and as the feldspars also occur irregularly in some of the large boulders, it is more probably a result of flow movement of the feldspar crystals in the semi-solid magma, at the time of its intrusion. Besides the above unfoliated types, foliated types are not uncommon, the foliation being probably a primary feature of the rocks, due to the same cause. The general direction of this foliation is approximately east to west and is parallel to the length of the phenocrysts.

Of particular interest is the fact that the dark anorthosite occurring in the eastern part of the area is traversed in all directions by thin veins of pegmatite. These ramify and send out branches which profusely cut the parent anorthosite just in the same way as a pegmatite cuts the parent granite. The contact is generally sharp but the veins frequently splay out as numerous thinner ones which end rather abruptly. There is every gradation from

these [illegible] in broad bands and dikes. The latter [illegible] presence of large [illegible] felspars. [illegible] generally have the same trend as the [illegible] foliation of the anorthosite [illegible] noted [illegible] in the [illegible] valley southeast of [illegible]. Here the prevailing [illegible] of the anorthosite masses can be traced to a northeast and southwest [illegible] from north to south.

The dark [illegible] are very common but they do not [illegible] way as the dark anorthosite as they do [illegible] variety. Like [illegible] these have a twofold [illegible] they have the same general east [illegible] west strike of the [illegible] relations are not uncommon.

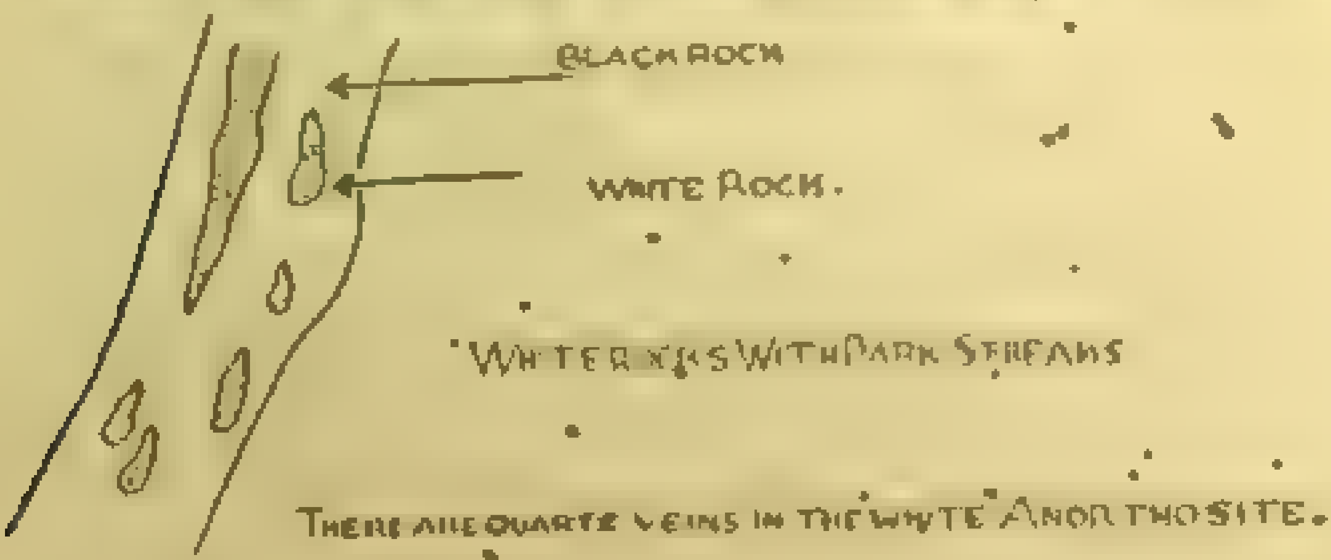
Anorthosite [illegible]

[illegible] rocks which contain a greater amount of ferromagnesian minerals than the preceding types. They are comparatively infrequent and only a few isolated [illegible] of the dark anorthosite have been [illegible] north of [illegible] and south of [illegible]. Pyroxenic varieties [illegible] in the western part of the area near Indrabil and Santuri. They [illegible] in the field by their dark [illegible] and the presence of [illegible] minerals. Microscopic examination [illegible] that the latter are [illegible].

[illegible] rocks

The occurrence of [illegible] rocks in the anorthosite [illegible], dikes and intrusive [illegible] has been already noted. These occur throughout the anorthosite [illegible] and also in the adjoining crystalline terrain. As a matter of fact most of the [illegible] rocks either within or [illegible] the anorthosite area in the northern part of the district of Bankura and the adjoining part of Manbhum are [illegible] of these [illegible] rocks. The dikes form characteristic ridges as they are more resistant to weathering than the intruded [illegible] gneiss. The rocks are hard, uniform, fine-grained and have a trap-like appearance. The weathered varieties [illegible] is generally absent, but there are [illegible] where the rocks have been converted into hornblende gneisses and amphibolites. Some of these are also garnetiferous.

ferous. Variations are found in the texture of these dark rocks ranging from fine grained granulitic varieties to coarse grained massive ones. Most of the dikes have an east-to-west trend with slight variations and sometimes they strike from north-west to south-east. It should be noted that this east to west strike of the dikes coincides with the strike of the anorthosite gneisses and with the direction of foliation of the older gneisses and schists. The dikes are almost always vertical and where they are inclined the dip is always towards the north. [illegible] the dikes have clean cut contacts with the anorthosite but there are instances where they appear as small lenses and irregular sheets with ill defined boundaries. The contact walls show evidence of [illegible] movement [illegible]. They may occur as thin and parallel bands close to each other in the mass of the labradorite rock and then the rock looks like a banded gabbro. This [illegible] may be cut by white granite veins and the whole complex is sheared and [illegible] gneissic [illegible]. The direction of foliation is parallel to the strike of the dikes, though local variations are found. In the neighbourhood of the [illegible] percentage of the dark minerals gradually increases towards the dikes and the [illegible] actually is transitional. (See plate I, [illegible].) These black bands grade into [illegible] and the [illegible] rock [illegible] streaky anorthosite or an anorthosite-gabbro transition rock. Within the mass of the black bands [illegible] there are [illegible] streaks and veins of the white rock. A beautiful instance is found [illegible] Sukhna (lat. 2[illegible], long. 8[illegible]) [illegible].



2

The sort of intimate association of anorthosite and the granite has been noted in other parts of the area. The two rocks interpenetrate each other in such a way that it seems as if both have intrusive relation to each other. But the more probable explanation is that the dark rock [illegible] and [illegible] up portions of the felspathic [illegible] which appear as white streaks, veins and bands.

The [illegible] and [illegible] south of Saltora [illegible] found to be intersected by aplite veins and dykes of the intrusive granite. [illegible] rock is similarly cut by pegmatite veins near Jemua.

[illegible]

Perhaps the most interesting group of rocks in the area under study besides the anorthosite itself is that of the granites and gneissic rocks. The commonest type is a pink rock whose colour is due to the presence of red or pink felspars. It has a gneissose appearance due to the alternate arrangement of the quartz and felspar bands. The pink granite or aplite [illegible] as dikes and has the same trend as the foliation of the anorthosite. It [illegible] in many places and in [illegible] leaves no doubt about its intrusive nature, as for example in the outcrop south of [illegible]. Some of the dikes are inclined towards the north. The granite cuts across the foliation of the anorthositic gneisses in the western part of the area but this relationship is only occasionally seen in the eastern part. In the former the granite is rich in epidote and [illegible] gneissose. The foliation of the rock in the eastern part is considered to be primary, induced at the time of its intrusion. The region lying to the middle of the eastern part of the area near the [illegible] valley has suffered great tangential pressure and some of the granite dikes here are [illegible] and look like quartzites. They have also been bent and contorted.

In one instance a red gneissose granite was seen to pass in the same strike to a darker variety which had a curious resemblance to the surrounding dark anorthosites. It seems probable that this peculiar change in colour, texture and mineralogical characters of the rock is due to the assimilation of anorthositic material by the granite at the time of its intrusion. The iron ores of the former have given rise to the dark colour of the resulting rock. This is the

only [illegible] of [illegible] where [illegible] has found them, [illegible] consider it as the result of [illegible] by granite. It can be regarded as a transitional rock [illegible].

There is [illegible] rock [illegible] superficial [illegible] mapping [illegible], especially when [illegible] and where mapping [illegible]. [illegible] within the [illegible] careful examination [illegible] pink [illegible]. They [illegible] rather abundant [illegible] anorthosite mass. [illegible] contains an appreciable percentage [illegible] than labradorite and [illegible].

Beside the above [illegible] types [illegible] which the feldspars are white and [illegible]. [illegible] granites of [illegible] type [illegible] been [illegible] the northern part of [illegible] road. The rock is [illegible] North of [illegible] exposures [illegible] the dark granodiorite [illegible] considerable [illegible]. This [illegible] that the [illegible] was [illegible] subsequent to the [illegible] of the [illegible] establish a correct sequence of the [illegible] there is no doubt that the dark [illegible] younger than the epidote granite. [illegible] section [illegible] is invaded by the dark [illegible] of the dark green [illegible] earlier than [illegible] hence occur also as [illegible] in the [illegible].

Finally, mention must be made of the pegmatites [illegible] occurrence of [illegible] has been already [illegible]. They

Pegmatites

are the final products of the differentiation of the original magma and have [illegible]. They are more abundant in the eastern part of the area.

Except the granosyenite [illegible] and the [illegible] granites, all the other types have also been noted outside the [illegible] such as the granodiorite gabbro and the [illegible].

is another type of granite-gneiss within the anorthosite, which closely resembles the granite-gneiss of the surrounding country. It has the appearance of an [illegible] of contact with the anorthosite. Its texture and its [illegible] appearance indicate that it is only a remnant of the country rock (see plate II, fig. 1). A beautiful example is seen [illegible] (lat. [illegible], long. 87° 5′ 30″). [illegible] of exactly of the same type and [illegible] on the west side of the road to Saltora from Kustolia.

Anorthosite dikes.

Instances of anorthosite dikes are not common in geological literature. Except in Canada, where Miller (Miller 1899) has recorded the occurrence of a number of anorthosite dikes of varying width, there is no other occurrence of anorthosite dikes known where these are fairly abundant. In the area under study, several such dikes have been found in the country rocks surrounding the anorthosite mass. On the eastern side there is no contact with the country rocks and the anorthosite body abuts against the broad [illegible] of the Damodar river. All the three varieties of anorthosite, viz., the white type, the dark type and the gabbroid type, are represented; of these the first type is the main. These dikes are fairly abundant in the region lying to the north-west of [illegible] at a [illegible]. Here the anorthosite forms ridges made up of [illegible] compact rock which dip at high angles towards the south. The strike varies from east and west to east-south-east and west-north-west, parallel to the direction of strike of the intruded granite-gneiss. Other less conspicuous dikes of anorthosite also occur between the main outcrop and the road. The anorthosite in all these exposures has a gneissoid appearance due to the parallel orientation of the constituents. The direction of orientation is generally from east to west. East of Barkona a succession of anorthosite dikes and granite-gneiss is found. Both these rocks are again intruded by the dark gabbro which has been converted into a hornblende gneiss. These dikes vary greatly in thickness, ranging from a few feet to several yards. The anorthosite in these localities is of the white felspathic type.

Dikes of anorthosite-gabbro have been found near Indrabil, cutting through the gneisses. In some places these dikes carry with

[illegible] contemporaneous bands of [illegible] gabbro [illegible] seen in the exposures beyond the [illegible] of Saltora [illegible] [illegible] The anorthosite [illegible] a hornblende gneiss of Dharwar age [illegible] as an inclusion in the granite [illegible] The [illegible] white type and the black [illegible] contrast (plate I, fig. [illegible]). Further south the anorthosite [illegible] the [illegible] and is itself cut by still younger quartz veins. It has [illegible] formation of [illegible] planes [illegible] (plate II, fig. [illegible]). At one place the [illegible] by a number of pegmatite and quartz veins [illegible] band of plagioclase rock. This band has all the characters of the [illegible] anorthosite and there is no reason to [illegible] of the [illegible] of anorthosite material [illegible] II, fig. 4).

Besides the anorthosite dyke a few lines of [illegible] rock [illegible] were found near the [illegible] Here the country rock consists of an interbanded series of [illegible] gneiss and felspathic gneiss. Dykes of the dark gabbro and [illegible] granite are also found, the latter also [illegible] Here the [illegible] run north to south instead of east to west parallel to the strike of foliation of the country rocks which [illegible] north and south. Some of the [illegible] and dip towards the west against the felspathic gneiss. They have a general resemblance to the anorthosites of the [illegible] type, but are [illegible] grained.

Country rocks. The country rocks occurring round the anorthosite mass and in which the anorthosite shows [illegible] intrusive relationship can be grouped under two groups, namely those belonging to the Dharwars and those belonging to the Bengal gneiss group.

The latter includes gneisses of [illegible] types intruded by dykes of younger granites, hornblende rocks, pegmatites and quartz veins. The former is represented by the [illegible] and [illegible] such as hornblende gneiss, spotted [illegible] schist, sillimanite [illegible] and sillimanite quartzites.

Starting from the eastern part of the area, going to the [illegible] of the anorthosite mass we first come across sandstones of Panchet and

ther of Kangsar, are faulted against the anorthosite. The older gneisses are first seen in the hills of Pabra (lat. 23° [illegible]', long. 8[illegible]° [illegible]' [illegible]"). The easternmost block is made up of the red granite and hornblende rock, but the other hills consist of felspathic gneiss and pyroxene gneiss. The latter forms most of the hills lying along the northern border of the anorthosite towards the west. It is interbanded with the Bengal gneiss which is, however, characteristically found in the low grounds. The strike of the foliation of these pyroxene rocks is remarkably constant and varies slightly from east to west. East of the Saltora inspection bungalow several outcrops of the Bengal gneiss are found in the anorthosite.

Mention has been made of the occurrence of hornblende gneiss (spotted) as inclusions in the Bengal gneiss behind the Saltora bungalow in connection with anorthosite dykes. The diagrammatic section on the opposite page shows the relationship of the different rocks.

The hornblende gneiss is a pale green phyllitic rock with large hornblende individuals which give the rock a spotted appearance. It is finely laminated and the laminae are much contorted and folded. It resembles the hornblende garbenschiefer of the German petrologists (Harker [illegible], p. [illegible]) and has resulted from the regional metamorphism of Dharwar sediments.

West of Saltora pyroxene and felspathic gneisses prevail, the former making up most of the hill masses which occur to the north of the road. It varies from a fine-grained dark-coloured type to a coarse-grained felspathic type in the same mass. The direction of foliation is east to west. An intrusive band of coarse-grained anorthosite was found in the foreground of the hill behind Santuri. There are phenocrysts of blue plagioclase in a white ground mass. The rock is foliated parallel to the foliation direction of the gneiss. South of the road near Santuri the rocks are granite gneisses of the type met with near the southern boundary of the anorthosite mass near [illegible]. East of Santuri there is a ridge of black hornblende rock. Within the anorthosite proper there are dykes of a fibrous hornblende schist and epidote granite, the former conforming to the foliation direction of the gneiss, while the latter cuts across the foliation and runs north to south. Besides these there are also quartz veins and pegmatites. Towards the west the strike of the granite gneiss veers towards a


N.
ANORTHOSITE
S

northeast to [illegible] west [illegible]. The anorthosite [illegible] here [illegible] and [illegible] west of [illegible]. The [illegible] anorthosite [illegible] have the same strike as that of the country rocks.

In the [illegible] valley [illegible] rocks of different types [illegible] white granite, [illegible] both the [illegible] have been [illegible] by the [illegible] the formation of a composite schist with [illegible] Dark [illegible] further [illegible] by the pink [illegible] dikes of anorthosite of the dark type [illegible] gabbro and hornblende gneiss are found in [illegible] gneiss. Massive [illegible] pink garnets [illegible] the [illegible] valley in the [illegible] of the anorthosite dikes [illegible] In an [illegible] near the [illegible] of the [illegible] between anorthosite and the dark coloured [illegible] gabbro is [illegible]

It seems that the [illegible] granite and [illegible] gneiss [illegible] the oldest rocks of the area representing the [illegible]. These have been [illegible] by the [illegible] granite gneiss and the anorthosite. The granite [illegible] by the anorthosite and the hornblende rocks [illegible] to be still younger [illegible]. The hornblende gneiss seems to be of different ages. Some of them are [illegible] associated with the granite gneiss and seem to be of the same age. While others belong to the period of anorthosite intrusion. Towards the west, i.e. towards the [illegible] railway station, the characteristic granite gneiss with [illegible] quartz and [illegible] veins carrying well developed tourmalines and bands of hornblende gneiss constitute the country rocks. The latter is perhaps intrusive as the bands are oriented parallel to the strike of the rocks, which is here west north-west to east south-east. Near the [illegible] railway station, a few dikes of anorthosite were found near the abandoned lime works. West of [illegible] a [illegible] dike of dolerite was seen running for a long distance from the north-north-west up to [illegible] in the south-south-east.

[illegible]

[illegible]

by hornblende gneisses. The latter form ridges and hummocks [illegible]. The characteristic east-west strike of the formation observed in the [illegible] of the anorthosite outcrop is again [illegible] further to the south-east near the B. N. railway and in the [illegible] the strikes vary between north-north-west and [illegible] south-south-east [illegible]. The dips are variable. [illegible] granite with pink felspar are found here and there. The [illegible] of [illegible] rounded rain-stones [illegible].

In the [illegible] river bed east of [illegible], a good section showing the nature of the country rocks is seen very near the motor road. The rocks run across the river bed from the north-north-west to the south-south-east, dipping towards the south-east. These consist of an interbanded series of [illegible] gneisses and hornblende gneisses. Both are very much contorted and the latter [illegible] in the presence of numerous thin quartzo-felspathic veins and streaks [illegible] with thin hornblende bands.

Further east, along the motor road the strike of the country rocks resumes the direction east-south-east to west-north-west, similar to the direction observed in the north-west, north of the anorthosite mass. East of [illegible] (lat. [illegible]; long. 87° [illegible]) from the 12th mile-post a number of dykes of the same anorthosite is seen to cut through the gneisses along the foliation planes, and stand out prominently in [illegible]. The anorthosite in all these exposures has a gneissoid appearance due to the orientation of the constituents, parallel to the foliation direction of the country rocks and the direction of elongation of the dykes. Dykes of a fine-grained [illegible] rock also occur in the same way as the anorthosite. The granite gneiss is not so much decomposed as in the western part of the area and [illegible] vertical [illegible] of the gneiss form characteristic ridges which run parallel to the anorthosite dykes. Near Narainpur (lat. [illegible] 28'; long. 86° [illegible]) further along the road towards the north-east, dykes of anorthosite and hornblende gneiss are again noted in the granite gneiss. As has been already pointed out the hornblende gneiss in the country rock does not seem to be of the same period of intrusion as the anorthosite and careful observations were made to find out if it

were not [illegible] than [illegible] gneiss. All doubts about [illegible] were set at rest by the examination of the stream section south-east of [illegible] inspection bungalow (lat. 2[illegible]) [illegible] where the hornblende gneiss was found [illegible] as dykes [illegible] to the granitic basement. The strike of the foliation [illegible] the hornblende gneiss and the [illegible] and [illegible] in such a way that it [illegible] that the [illegible] of the magma has forced [illegible] rather than that these [illegible] are [illegible] the granite gneiss. The [illegible] character of the [illegible] out by the nature of the [illegible]. The [illegible] of the same type as has been [illegible] and [illegible] appearance on weathered surfaces. [illegible] the hornblende gneiss and the granite gneiss [illegible] of the two. The strike of these [illegible] approximately east to west or east-south-east to west-north-west.

From [illegible] a road [illegible] Saltora [illegible] (lat. 2[illegible], long. 8[illegible]). A short [illegible] there is a stream in which [illegible] bands of hornblende gneiss are [illegible]. [illegible] Bengal gneiss found in all these [illegible] resemblance to that found near Santar[illegible] [illegible] ance particularly in weathered [illegible] from the gneisses found along the [illegible] near Saltora. This granite gneiss extend[illegible] from the [illegible]-Saltora road and is intruded [illegible] gneiss are also amphibolite as has been already noted near [illegible] and [illegible]. Granite gneiss prevails towards Saltora and forms [illegible] ridges which generally run east and east-south-east to west and west-north-west. These ridges are quite abundant near [illegible], long. [illegible]). The granite gneiss has a pink [illegible] but [illegible] bands of younger granite with white felspars. [illegible] the [illegible] mass lying to the north-east of the [illegible] there is a long ridge of granite gneiss [illegible]. No definite intrusive contact was found and the [illegible] not regular (see plate 2, fig. 1). The junction between [illegible] is in most places hidden by alluvium. In the [illegible]

[illegible] between [illegible] and the [illegible] as revealed near [illegible], it [illegible] clear that this [illegible] of granite [illegible] a remnant of the country rock. It [illegible] east and [illegible] to west and west [illegible] west [illegible] towards the [illegible].

[illegible] with [illegible] long. [illegible] further [illegible] forms the [illegible] country rock. [illegible] further [illegible] are [illegible] augen [illegible] and [illegible] of the [illegible] the [illegible] is found near [illegible] at [illegible]

[illegible] rocks found [illegible] area [illegible] two types, [illegible] and [illegible]. The former [illegible] of the [illegible] the [illegible] The former [illegible] the [illegible] have also been found in the [illegible] near [illegible] The [illegible] of the area [illegible] that these [illegible] with the [illegible] granite, [illegible] and quartz veins which [illegible] the anorthosite body.

It [illegible] that [illegible] of the type described from this [illegible] towards the [illegible] west and forms the base [illegible] rock of [illegible] Here the [illegible] is intruded by [illegible] of porphyritic granite which [illegible] characteristic dome shaped [illegible] found near [illegible] long. [illegible] 45 [illegible] intruded by a dark hornblende [illegible] resembles the gabbros associated with the anorthosite. The [illegible] by the [illegible] The occurrence of these gabbro [illegible] far away from the main anorthosite outcrop, indicates that the anorthosite [illegible] and [illegible] the [illegible] some parts of the surrounding [illegible], in spite of the tremendous extent of [illegible] which the region has undergone.

[illegible]

VI. [illegible] THE COUNTRY ROCKS

Labradorite rocks.

[illegible] made out from a [illegible] by granular texture [illegible] (See plate III, [illegible]) [illegible] (Plate III, figs. [illegible] and [illegible]) [illegible] Rosenbusch. [illegible] grey appearance. Though the feldspars are [illegible] feldspars [illegible] more common, but both Albite and Per[illegible] same individual. Combined Carlsbad and [illegible] been noted, the extinction [illegible] labradorite. The twin lamellæ are [illegible] and do not extend over the entire section. They are bent [illegible] and the extinction is not uniform. When [illegible]

[illegible] of [illegible] and [illegible]. According to Clarke (1904) [illegible] epidotisation represents a reaction between felspar and the ferromagnesian constituents which releases quartz, while scapolitisation requires lime which is liberated by the change of pyroxene to amphibole. Lime and soda from the felspars combine with the chlorine of [illegible] to produce scapolite. Small quantities of [illegible] ferromagnesian constituents are present in most of the amphibolites. The dark ferromagnesian constituents are pyroxene ([illegible]), amphibole, biotite, ilmenite and garnet. These seldom exceed [illegible] of the total quantity of minerals. These are not uniformly distributed in the rock but generally occur in clusters. Ilmenite and hornblende usually occur together and both may surround pieces of ilmenite. Biotite sometimes completely surrounds the ilmenite and may be intergrown with it (plate IV, fig. 2). Sederholm ([illegible], p. [illegible]) has given several instances of the formation of biotite at the boundary of plagioclase and ore in [illegible] and [illegible]. The biotite occurs between the ilmenite and the plagioclase and has probably originated by a reaction between the two minerals during post-magmatic stages when volatiles were more abundant. Biotite has brown pleochroism and is generally fresh. In some specimens it has altered to penninite. The primary hornblende has the following pleochroism: X—yellow, Y—bluish green, Z—greenish blue or, X—yellowish green to Z—dark green. In some rocks both biotite and hornblende have been chloritised. The pyroxenes, both rhombic and monoclinic, occur as large individuals and also as small granular aggregates. They are often altered and show different stages in amphibolisation. [illegible] are thrown out towards the periphery where they coalesce together into granules of ilmenite. The rhombic pyroxene is faintly pleochroic and the bluish green colour of the rhombic variety is closely similar to the same colour of the monoclinic one. Within the aggregates of granulitic pyroxenes some show the pleochroism of hypersthene, but otherwise in respect of cleavage, schiller inclusions and [illegible], all seem to be of the same type. The rhombic pyroxene often shows inclined extinction and the angle may be as high as 15 or 20°. The monoclinic pyroxene is in some specimens altered to [illegible]. Garnet does not occur in all the specimens, nor do the specimens in which it occurs show the slightest

evidence of [illegible] metamorphism. [illegible] has [illegible] light pink [illegible] pyroxene. It does not show any reaction rim but [illegible] and [illegible] of quartz, [illegible] and amphibole. Narrow band of amphibole [illegible]. It seems [illegible] the garnets have formed at the expense of [illegible] pyroxenes [illegible] been [illegible] altered to amphibole. The [illegible] has been [illegible] in the [illegible] of South India [illegible] p. 101).

[illegible] without exception in all [illegible], varying in [illegible]. West of [illegible] dark gabbro.

Zircon is very rare in the anorthosites and apatite has not been found [illegible]. In the [illegible] stream section below the bridge on the [illegible] road, slices of the anorthosite [illegible] show the presence of a considerable amount of quartz [illegible].

A peculiar [illegible] rock was [illegible] near [illegible] the Bengal [illegible] which resembles the [illegible] in physical appearance but [illegible] quartzite. Microscopic examination shows that it is a granulated quartz-felspathic rock with [illegible] disseminated [illegible] and [illegible] plagioclase (labradorite) [illegible] and [illegible] plagioclase are noted. The other constituents are [illegible] with a [illegible]. The rock [illegible] anorthosite and may represent a [illegible]. Mention may be made here of the [illegible] and sheared bands of a rock [illegible] anorthosite [illegible] with [illegible] which on microscopic examination proved to be crushed granulites.

The specific gravity of the labradorite [illegible], and that of the dark anorthosite is [illegible].

[illegible]. This rock is [illegible] labradorite rocks and has a specific gravity of [illegible]. In hand specimens it is a fine-grained white rock with granular texture. Microscopic examination shows the presence of [illegible] plagioclase [illegible] and [illegible] greater degree of kaolinisation than in the case of the labradorite rocks. The ferric

minerals such as olivine, pyroxene, and biotite have also been altered. Epidote and zoisite have largely replaced the feldspars and the ferric constituents. The chlorite has pleochroism from pale yellow to green and has ultra blue birefringence. It is a positive pennine.

The dark coloured anorthosites grade into a gabbroid type in some places such as near [illegible] lat. [illegible], long. [illegible], and [illegible] lat. [illegible], long. 87° [illegible] 15'.

Anorthosite gabbro.

In the field these can be distinguished from the dark anorthosites by their darker colour, coarser grain and by the presence of altered ferromagnesian minerals such as olivine and pyroxene. In these rocks the plagioclase [illegible] beautiful [illegible]. There are [illegible] individuals, and by [illegible] flakes of [illegible] and granules of hornblende and pyroxene. The pyroxenes are [illegible]. Large pieces of olivine are found with well developed fractures. The mineral is generally serpentinised and [illegible] by the [illegible]. Serpentinisation has proceeded along cracks which extend across the mineral forming the reaction [illegible]. The reaction rims consist [illegible] of hypersthene with characteristic pleochroism and low polarisation colours followed by [illegible] with lower polarisation and then by garnet. Sometimes there is a narrow zone of feldspar between the pyroxene and the garnet and the garnet is spongy with numerous small inclusions of quartz and amphibole. The pyroxenes have been amphibolised along their outer margins (see plate IV, fig. 1). According to Bowen and Anderson (1914, pp. 487-500) olivine crystals are resorbed with the development of reaction rims of enstatite during the normal crystallisation of a basaltic magma. By further recrystallisation due to subsequent metamorphism the mineral has become granulitic. Harker (1909, p. 241) has described similar reaction rims around olivine in the gabbros of Lake Champlain. Adams (1893) has described rims of [illegible] pyroxene and hornblende, round olivine in the anorthosites of Saguenay. These reaction rims always occur between the olivine and the feldspar. Other instances have been recorded in the peridotites of the Cortlandt series (Williams 1886), in the Lizard gabbro (Teall 1888), and in the norites of South India (Holland 1900).

The formation of garnet at the expense of pyroxene is well seen

in this rock. Possibly there has also been a reaction between the pyroxene and the felspar according to the following equation of [illegible] and Grubenmann [illegible] :—

Diopside + anorthite = garnet + quartz

The garnet in fig. 1 of plate V has numerous inclusions of amphibole and quartz. It occurs between olivine seen on the right and a band of hypersthene seen on the left. Amphibolisation in these rocks seems to have occurred later than the plutonic metamorphism under the conditions of which the garnet was developed.

The anorthosite-gabbro occurring near [illegible] (lat. 23° [illegible]; long. 86° [illegible]) has the composition of a norite, but differs from the dark-coloured granulitic gabbros in having a coarse, unevenly crystalline texture. The felspars are of the same type as found in the anorthosites and show beautiful schillers of [illegible]. The twin lamellae are bent and contorted. Hypersthene is the most abundant of the ferromagnesian constituents. It has not suffered any granulation, is full of schiller inclusions and has altered to amphibole particularly along the periphery. Some are of the bronzite variety characterised by a sub-metallic lustre, lack of pleochroism and weak birefringence. The other minerals are brown biotite and ilmenite.

Dark [illegible] and Norites.

As has been noted previously in connection with the field relations and characters of these rocks, these granulite-gabbros vary in size from narrow schlieren to massive dyke-like zones. They are very hard, compact and uniformly fine-grained and have a perfectly black colour with sometimes a greasy lustre. But some of these have developed a foliated structure and have been converted into amphibolites and hornblende gneiss. They occur outside the anorthosite outcrop, where sometimes they can be distinguished from the older hornblende gneiss by their peculiar greasy lustre and compact granulitic appearance. The foliated varieties are often garnetiferous. The non-foliated varieties have an uniformly granulitic texture, though there is considerable variation in the dimensions of the constituents (plate V, fig. 2). In some granulation has taken place along certain zones. The principal constituents are plagioclase, pyroxene (both monoclinic and rhombic), hornblende, biotite, ilmenite, etc. In the schistose varieties the amphiboles have

attained increasing size by the absorption of the inner rims of a granulitic aggregate of augite pyroxene and the smaller inclusions are thrown out towards the periphery. The light greenish tinge of both the monoclinic and the rhombic pyroxenes is strikingly similar and both are pleochroic. Hornblende develops after both. The rhombic pyroxene is in subordinate amount.* It seems to be secondary and derived from the monoclinic pyroxene. Hypersthenization of monoclinic pyroxene has been observed in the Charnockite series of Cochin State (Records [illegible] 1916, p. [illegible]). Some of the foliated varieties have also undergone a great deal of shearing resulting in the granulation of the hornblende. The hornblende is thoroughly fractured in these specimens (Plate V, fig. 8).

A number of microscopic sections of specimens from the junctions of the granulitic gabbro and the amphibolites were examined in order to find out the mode of origin of the former. This examination leaves no doubt about the correctness of the explanation arrived at from a study of the field relations. The junction is often sharp in some places but generally there is no definite boundary line between the mineral bands of the two rocks and there is an interpenetration of the minerals belonging to the adjacent bands (see plate V, fig. 4). Slides of the banded amphibolite with bands of the dark rock show that the two bands are really not different, consisting chiefly of the same minerals, such as pyroxene and hornblende together with [illegible]. In some sheared varieties the grains are smeared, fragmented and crushed. The shearing has taken place subsequent to the formation of the amphiboles which are fractured and distorted. The amphiboles are altered to epidote and chlorite. Epidote fills up the microscopic cracks in the rocks and is associated with sphene. The feldspars have also been granulated and the large relic feldspar indicate the size previously attained by the minerals. Some of the rocks are garnetiferous. In the banded amphibolites of Sakleshpur garnets have attained very large dimensions in one part of the outcrop. The other minerals have also large dimensions, so that the rock is very coarsely crystalline. The

* [illegible] cracks [illegible] parallel [illegible]

garnet has a pink colour and includes blebs of hornblende and biotite and is also fringed by them. Inclusions of these also occur inside the garnet representing the schiller inclusions of the original pyroxenes.

In the gneissic variety the granulitisation of both the pyroxenes is more complete, and due to the directed pressure the minerals show granulated borders and the felspars show strain shadows and wavy extinction.

Besides the above, dykes of hornblendite and pyroxenite were also noted, the former near [illegible] and the latter in the Dangra valley. The first rock originally consisted chiefly of hornblende, which has extensively altered to chlorite, epidote and sphene. The pyroxenite consists of pale green augite with well developed cleavage, hornblende and garnet with a small quantity of plagioclase felspar. The garnet contains inclusions of hornblende. The pleochroism of the hornblende is as follows:—

X—Yellowish green Y—Olive green Z—Deep green

These rocks appear to be extreme basic varieties of the granulitic gabbros. The average specific gravity of the granulitic gabbros varies from 3.11 to 3.2.

The gneissic variety of the gabbros resembles the other hornblende gneiss which occurs chiefly as dykes and lenses in the granite gneiss surrounding the anorthosite and varies from a plagioclase pyroxene gneiss to typical hornblende gneiss. In the former the pyroxene passes into hornblende with pleochroism varying from brownish yellow to pale green or from brownish green to yellowish green. The plagioclase is of an acid type whereas it is always labradorite in the gabbros and the rocks contain an appreciable amount of quartz. Granulitic structure is also generally absent.

Granites, pegmatites and [illegible] anorthosites.

The mode of occurrence of these rocks has been discussed in the section under field relations. The granites belong to two types; the one is characterised by the presence of pink felspar, while in the other the felspar is white and forms augen. The former is more prevalent. It has assumed a gneissose structure in most places,

Thin sections show the presence of a large amount of Deutero[illegible] (Sederholm, [illegible]) or [illegible] (Tom Barth, [illegible]), besides quartz, a small quantity of small plagioclase feldspars, and myrmekite in the granulated zone surrounding the perthites. The inclusions in the latter sometimes assume recognisable size with well developed twinning. Plagioclase is not always present and orthoclase with straight extinction on cleavage lines is present in many cases. Microcline is rare. There is a very small quantity of ferromagnesian minerals, such as green biotite and hornblende. The former is elongated parallel to the direction of foliation. When altered it passes into chlorite. Hornblende is altered into a fine aggregate of serpentine and [illegible]. Other secondary minerals are epidote, [illegible], sericite and calcite. The accessory minerals are zircon and ilmenite. Epidotisation has proceeded considerably in some giving rise to a variety of epidote granite. Epidote is primary in the sense that it formed under hydrothermal conditions.

The perthitic structure is not evident in all the sections, but it is often revealed by the kaolinisation of the included plagioclase. The gneissic structure is due to the alternate and sub-parallel arrangement of the quartzose and the feldspathic bands. Quartz is clear but the feldspars have wandering extinction, and have undergone a much greater degree of crushing and granulation in the crushed varieties.

The augen granite has suffered a great deal of shearing stress as is seen in the field and shows the effects of crushing in thin slices. Both plagioclase and orthoclase occur and show undulose extinction. Large [illegible] feldspars form "eyes" enclosed by granulation [illegible]. Myrmekite is present in this zone. The constituents have a parallel arrangement.

The intrusive nature of the granite is proved by the mode of occurrence of the dykes. Samples were taken from the junction between anorthosite and a pegmatitic variety of this granite. The contact zone is marked by the presence of granulated quartz and feldspar and a dark coloured chloritic mineral occurring interstitially. The granitic portion shows large individuals of perthites. The plagioclase inclusions of these perthites form small drops or blebs and occasionally pass into veinlets. The drops have a long shape and pass into elongated strings. Incipient microcline twinning is seen in some,

and [illegible] are present. The former has altered into [illegible] but the latter very rarely into leucoxene.

Sections of rocks taken from the [illegible] between the granodiorite and anorthosite show [illegible] clear [illegible] between the two. The [illegible] felspar of the anorthositic portion [illegible] but [illegible] the other portion [illegible] is [illegible] associated with [illegible] and [illegible]. The [illegible] of this rock took place at the time of [illegible].

Though these [illegible] they always occupy sheared zones in the anorthosite and [illegible] into the latter rather [illegible] at the [illegible]. The [illegible] are traversed by a network of [illegible] and [illegible] the [illegible]. These facts [illegible] the [illegible] of the granodiorite and [illegible] from the same [illegible] which produced the anorthosite [illegible] and [illegible] subsequently invaded the earlier formed rocks. In [illegible] the occurrence of [illegible] is [illegible] of an earlier formed rock by the [illegible] of the [illegible] magma. The [illegible] the materials of the granodiorite [illegible] state [illegible] account [illegible] the rock [illegible] crushed and [illegible] the [illegible]. The [illegible] of [illegible] and the mineral composition [illegible] from granodiorite to pegmatite are strong arguments in favour of the explanation [illegible].

But although the granodiorite [illegible] is supposed to have originated from the same magma [illegible] formed at different depths and subsequently invaded the overlying rocks, [illegible] happened is shown by the occurrence of [illegible] which [illegible] is made [illegible] under the microscope [illegible] is seen to consist of all the minerals [illegible] characteristic of granodiorite, but the plagioclase felspars are of two different types, namely [illegible] and [illegible] (See [illegible]).

The [illegible] felspars [illegible] observed in the [illegible] anorthosites. The junction between these minerals and the rest of the granodioritic portion is [illegible]. These felspars show more or less straight edges, but the granodioritic portion [illegible] crushed,

with the formation of myrmekite and development of cross hatching and undulose extinction in the alkali felspar. Hornblende is altered to penninite, [illegible] and epidote. The materials of the last named mineral are derived from both hornblende and plagioclase felspar. The occurrence of labradorite in this rock cannot be explained by any other hypothesis than that of hybridism. Miller (1919, pp. [illegible]) has described the occurrence of [illegible] from the Adirondacks to which he gave the name [illegible]. But this idea has been disproved by [illegible] ([illegible]), and Alling ([illegible]) who regard the keene-gneiss as a transition rock between the anorthosite and the granite. Moreover the results of Bowen's experiments (Bowen 1922) indicate that 'granite magma saturated with [illegible] and plagioclase cannot dissolve basic plagioclase but can only react with it and convert it into more acid plagioclase.' In the present area of anorthosite no transition rock has been met with in spite of the most detailed field work and the dyke, the rocks of which are under description, is the only one of its kind. If the material of this dyke had been in a fairly advanced stage of crystallisation it could not possibly react with the plagioclase felspars of the anorthosite xenoliths it caught up, during its upward passage.

The specific gravity of the acid [illegible] granite is 2.[illegible]9, while the specific gravity of the granodiorite is 2.76 and that of the epidote granite is 2.98.

It should be noted in this place that like the anorthosite and the gabbro, the granites also occur as dykes within the country rocks surrounding the anorthosites in many places.

Compared to the large area covered by the anorthosite and by the gabbros, the granitic rocks are quite inconsiderable in extent and bulk. If the granites are due to a separate period of intrusion they should be expected to cover a large area. The small bulk also suggests a residual origin.

Country rocks.

Granite Gneiss.—This is the most prevalent type of gneiss. It is generally of a pink colour and coarse texture. The specific gravity is also high, e.g., 2.[illegible]. It is a typical microcline gneiss and agrees closely with the description of the Chota-Nagpur granite gneiss given by Dunn ([illegible]). It consists of quartz, microcline perthite, orthoclase in small quantity

plagioclase with antiperthite in some cases, biotite, hornblende, ilmenite and zircon. The perthite structure is beautifully developed. It is of the type of film perthite (see plate VI, fig. 3) of Andersen (1928). In some, large porphyroblastic individuals are set in a base consisting of granulitic quartz and feldspar. Myrmekite is well developed in these.

Quartz-[illegible] Gneiss.—This rock occurs in many places along the northern boundary of the anorthosite near Saltora. It is much decomposed and is closely associated with pyroxene and hornblende gneisses. The rock from Saltora has a granulitic structure as a result of crushing. There are different types of recrystallised quartz and granulated feldspars. Occasional large grains of feldspars also occur. Plagioclase of the acid variety is present. Myrmekite is noted. An interesting constituent is a little of [illegible] variety is also found. [illegible] found near B[illegible] near the [illegible] boundary, the mineral is decomposed into a brown [illegible] substance. Small granules of clinozoisite are present. Iron ores are [illegible] and form together with the granules of [illegible] along parallel lines. These with the quartz-felspar bands give the rock its gneissic appearance. The iron ores are extensively altered to limonite which has stained the rock and has filled up the cracks in weathered specimens. Small biotite flakes occur abundantly with their longer axes parallel to the direction of foliation. [illegible] of sizes and forms 'eyes'. The rocks as a whole have a quartzitic aspect.

Amphibolites.—These rocks occur near Saltora and are invaded by the gneiss noted above and also by the anorthosite.

Spotted Hornblende Gneiss.—It is really a crushed quartzite with a small amount of feldspar and large porphyritic hornblendes which were broken along their outer margins at the time of foliation. Small granules of hornblende and mica are scattered throughout the [illegible] and are arranged along directions of foliation round the porphyroblasts of hornblende. See plate VI, fig. 4.

Pyroxene Gneiss.—These are plagioclase pyroxene gneiss with secondary hornblende. The pyroxene belongs to both the monoclinic and the rhombic varieties. The rhombic pyroxene is schillerised and seems to be secondary after the monoclinic variety [illegible] the

pyroxene are uralitised along their margins and along the cracks in the interior. Biotite and ilmenite are the other minerals. Apatite and zircon are accessories. Both quartz and felspars have undulose extinction and the twin lamellae of the latter are bent. In mineral composition these rocks resemble the charnockites but they have not the least physical resemblance and show many metamorphic characters both in the field and in the microscopic sections. Ordinary orthogneisses by progressive metamorphism have developed into a hypersthene-bearing gneiss (see Groves, 1935).

The sillimanite-biotite gneisses carrying quartz, felspar (both orthoclase and plagioclase) require no further description.

The dolerite dykes are of the type which occurs in the neighbouring coal field, i.e. they are of Rajmahal lava age. They consist of plagioclase ophitically or sub-ophitically enclosed by the titaniferous pyroxenes and iron ores. Chlorite has developed at the expense of pyroxene and felspar and after what appears as cryptocrystalline glass. The presence of this glass distinguishes these from the Newer Dolerites of Singhbhum described by Dunn [illegible], Pt. 2, p. 97).

VII. Chemical Characters of the Chief Types

The pure labradorite rock has the composition stated below. This agrees very well with the composition of a labradorite rock described by Kolderup from Bergen.

	1	2
SiO_2	52.20	52.90
Al_2O_3	27.48	28.[illegible]
Fe_2O_3	1.33	0.10
FeO	0.56	0.41
MgO	0.14	0.27
CaO	13.06	12.17
Na_2O	[illegible]	4.92
K_2O	[illegible]	0.56
TiO_2	Trace	
P_2O_5	0.02	
H_2O	[illegible]	
H_2O at 110° C	0.22	
	100.00	99.81

1 Labradorite rock from below the bridge on the [illegible] Bankura road near the 7th mile post

2 Labrador[illegible] rock from Bergen Norway (Washington 1917, p. 302)

On calculation, the normative composition of the former indicates a plagioclase with about [illegible] An, which confirms the composition arrived at from the maximum extinction angle and the refractive index

The dark anorthosites have the composition stated below —

	1
SiO_2	[illegible]
Al_2O_3	27.72
Fe_2O_3	4.90
FeO	2.60
MgO	0.88
CaO	12.68
Na_2O	3.12
K_2O	Traces
TiO_2	Traces
H_2O (+)	[illegible]
H_2O (–)	[illegible]
	[illegible]

1 Anorthosite from the [illegible] near the road to [illegible] (Chatterjee, 1930, p. 61.)

The oligoclase from [illegible] has the following composition

SiO_2	[illegible]
Al_2O_3	[illegible]
Fe_2O_3	[illegible]
FeO	[illegible]
MgO	[illegible]
CaO	[illegible]
Na_2O	[illegible]
K_2O	[illegible]
TiO_2	[illegible]
P_2O_5	[illegible]
H_2O > 110° C	[illegible]
H_2O at 110° C	[illegible]
	100.00

The normative composition indicates a plagioclase with [illegible] An

Composition of the granite from near Me[illegible]

SiO_2	77.[illegible]
Al_2O_3	[illegible]
Fe_2O_3	3.20
FeO	0.56
MgO	[illegible]
CaO	[illegible].44
Na_2O	2.[illegible]
K_2O	5.10
TiO_2	Traces
P_2O_5	Traces
MnO	.01
$H_2O > 110°C$	.34
H_2O at 110°C	.26
	100.[illegible]

The dark coloured granulite (gabbro) … has the following composition, which compares favourably with the composition of a norite from Aberdeenshire:—

	1	2
SiO_2	48.[illegible]	48.58
Al_2O_3	14.[illegible]	13.82
Fe_2O_3	[illegible]	1.11
FeO	11.28	12.78
MgO	[illegible]	5.21
CaO	[illegible]	9.43
Na_2O	2.[illegible]	2.87
K_2O	.7[illegible]	.70
TiO_2	2.[illegible]	3.44
P_2O_5	.31	.04
$H_2O > 110°C$	.47	.36
H_2O at 110°C	.16	.06
	100.[illegible]	10[illegible].18

The greater amount of P_2O_5 in 2 is due to the presence of apatite in the mosaic of basic labradorite (p. 57 Chemical Analyses of Igneous Rocks, Metamorphic Rocks and Minerals, H. M. Stationery Office, 19[illegible]).

Two specimens of the country rocks were analysed, one belonging to the gneiss found near [illegible] and the other belonging to the spotted hornblende rocks intruded by the former. On account of the large amount of hornblende in the latter its analysis does not indicate a definitely sedimentary origin and there is only an excess of quartz and an excess of potash over soda.

		1	2
SiO_2	...	71·22	[illegible]
Al_2O_3	...	15·63	[illegible]
Fe_2O_3	...	2·42	[illegible]
FeO	...	1·80	traces
MgO	...	·56	[illegible]
CaO	...	·60	[illegible]
Na_2O	...	3·07	[illegible]
K_2O	...	4·07	[illegible]
TiO_2	...	·46	
P_2O_5	...	·05	
MnO	...	1·07	
$H_2O > 110°$ C.	...	·40	[illegible]
H_2O at 110° C.	...	·07	[illegible]
		100·39	100·87

The first rock is, as has been already noted, a [illegible] rock and its specific gravity is 2·52.

VIII. Origin and Inter-relations of the Chief Types

A consideration of the field relations of the different rocks occurring within the anorthosite and genetically related to it, together with their microscopic characters and chemical affinities, lead to the conclusion that all the rocks ranging in composition from the dark granulitic gabbros to the pegmatite through the anorthosites and granodiorites form a series derived by differentiation from a common parent magma. From the greater prevalence of the gabbroid rocks and the very small development of the granitoid facies, it may be reasonably concluded that the original magma was gabbroid in composition and was intruded under a great depth of cover leading to slow

crystallisation. The femic constituents began to solidify earlier and together with some plagioclase material gave rise to the dark gabbro bodies varying in size from mere specks to huge dikes and lenticular masses. The irregular arrangement of these dark segregations as [illegible] bands in the anorthosites is such as to force one to recall the convection [illegible] of cauldrons suggested by Grout (Grout, 1918), [illegible] and their sharp contacts clearly point to their origin by segregation. In the majority of cases they present an intrusive relation to the anorthosite mass and to the country rocks, but this may be due to a later [illegible] effect which forced up the material of the basic parts which settled towards the bottom (Grout, 1918, p. [illegible]). The sharp contact of these [illegible] bands and their intrusive mode of occurrence are due to deformative movements in the plastic mass during further intrusive movement.

When the crystallisation of the plagioclase felspars and the settling of the crystals had advanced to a considerable extent, the magma was subjected to deformative stresses arising out of mountain-building movements and the felspathic differentiate was displaced (Cf. Bowen, 1928, p. [illegible]). The interstitial liquid already partially expelled by a straining-off process would be squeezed out along the narrow channels between the closely compacted crystal meshes, where it would be under the influence of great shearing stress at the time of further compaction with advancing crystallisation. Thus would originate the numerous pegmatitic veins which traverse the anorthosite rocks and ramify in different directions and the sheared granodiorite zones. According to Bowen, anorthosite masses of extreme purity arose in this way by the squeezing-out of the interstitial liquid, and the protoclastic structure which invariably characterises these rocks was developed as a result of the close packing of the crystals (Bowen, 1928, p. [illegible]). The granulitic structure of the anorthosite and some gabbros is due to differential movement at the time when the crystallisation was still in progress. The residual liquid may behave like a separate intrusive body although it is derived from the same parent magma. Looked at in this way the granite dikes occurring in the anorthosite may be regarded as squeezed out residual portions of the magma owing their position to the phenomenon of auto-intrusion.

DISCUSSION OF THE FIELD AND LABORATORY DATA IN THE LIGHT OF WORK DONE IN OTHER AREAS

According to Bowen (1917), [illegible] rock formed by the gravitative accumulation of [illegible] feldspars from a [illegible] magma, the residual [illegible] of granite or syenite. This was [illegible] by Miller [illegible] to whom the [illegible] and not a differentiate of the parent magma. [illegible] that the [illegible] and [illegible] from a zone of gabbro grading into [illegible] by the residual granitic portion of [illegible] downward into gabbro forming the [illegible]. [illegible] and [illegible] after a careful study of the [illegible] that the granite is derived from the [illegible] magma. [illegible] syenite [illegible] are considered as the [illegible] has found numerous [illegible]. The rocks of these [illegible] of the mother liquor, which were expelled to form the masses of [illegible] granite. This [illegible] of Bowen's [illegible] hypothesis, but the [illegible] out of the mother liquor [illegible] by Bowen (1928). In an earlier paper [illegible] suggested the origin of anorthosite [illegible] of the residual liquor (Bowen [illegible], p. [illegible]) [illegible] to the view of [illegible] and syenite granite as a result of [illegible]. The mafic facies of the [illegible] greater [illegible] of crystallization [illegible] out of the residual liquid [illegible].

More recently Grout and [illegible] forward evidence to show that in the case of the [illegible] gabbro the anorthosite formed early and was [illegible] with [illegible] different [illegible] of the gabbro [illegible]. "The late red rock phase of the magma shattered and [illegible] lated some anorthosite [illegible] XVI, but [illegible] Guide Book, 27 1933, p. 71.)

Balk's ideas fit in nicely with the [illegible] facts observed in connection

with the [illegible] of Bengal. The schistose zones consisting of [illegible] and [illegible] granulites represent the granitic residual liquid. The foliation of these rocks is considered to be of primary origin. Miller has thoroughly discussed the origin of foliation in the [illegible] rocks of New York. In the present area [illegible] the differences in the degree of foliation and granulation in different parts of the anorthosite body and the [illegible] gabbros show that these were due to the movements of the magma before its final consolidation. [illegible] at least [illegible] of subsequent dynamic metamorphism [illegible] further accentuated the original differences in foliation.

The [illegible] of these rocks, such as granulation [illegible], bent twin lamellae of the felspars, absence of [illegible] of the felspars and their [illegible] freshness, are [illegible] in the rocks show evidence of [illegible] metamorphism in the secondary origin of garnet and some of the hypersthenes. [illegible] hypersthene appears to be primary in the gabbro [illegible] but the [illegible] cleavage, alteration products, and the optical continuity between the hypersthene and the [illegible] pyroxene together with the inclined extinction of the [illegible] strongly that it is secondary in origin in some of the rocks. It [illegible] be noted that secondary hypersthene also characterises the other pyroxene [illegible] of the country lying to the north of the anorthosite. [illegible] has described the development of secondary hypersthene in the [illegible] associated with the [illegible] of [illegible], pp. [illegible]).

It is believed that the anorthosite rock never existed in a liquid state, but the thin veins of anorthosite in [illegible] gneiss, and the presence of [illegible] varieties show that in certain places it contained a [illegible] amount of liquid in between the crystals, which gave the rock its power of flowage. It is for this reason that the [illegible] felspars are embedded in a granulosed base. The oligoclase [illegible] represent [illegible] phase of the anorthosite in which the labradorites were [illegible] by the liquid.

A striking [illegible] feature of the anorthosite body is the variation in the quantity of the [illegible] constituents present in its different

parts. The increase in the quantity of the ferric minerals is accompanied by a greater extent of sericitization of the felspars and the rocks become darker in colour. Even within the masses of the darker varieties there is a good deal of variation in the distribution of the ferric minerals, and occasionally the rocks pass into gabbroid types. This is no doubt accounted for by the differences in the rate of the settling of the femic constituents in different parts of the magma which depended upon the rate of crystallization and viscosity. The white varieties of the anorthosite are due to a more efficient settling of the femic minerals at an earlier stage of crystallization of the felspars so that the latter have not been so completely sericitised.

IX. STRUCTURE OF THE INTRUSIVE AND ITS PROBABLE AGE AND AFFINITIES

The nature of the outcrop of the anorthosite belt and the parallelism of its strike with the strike of the foliation of the older gneisses which surround it, show that it was intruded as an elongated sheet-like mass between the gneisses. The occurrence of the anorthosite and gabbro dikes away from the main body, however, suggests that it has widened in depth and may have the form of a [illegible] laccolith. The original extent of the mass toward the east cannot be known as here it has a faulted boundary with the Gondwanas which lie beneath the [illegible] basin. The total area of the visible mass is approximately 100 square miles.

The intrusion is of pre-Cambrian age and is of the same period as the Charnockite series of South India to which it presents many mineralogical similarities ([illegible]). [illegible] the anorthosite rocks to be genetically related to the charnockite but yet anorthosite has not been found anywhere near the charnockites of South India. Later work in the Kalahandi State, where both charnockite and anorthosite occur associated with granitoid gneiss (Walker, [illegible], p. 7) might bring out the relationship if any between the two rock groups. The majority of the anorthosite bodies belong to the pre-Cambrian and this may be due to the fact that these rocks require a great depth of cover for their formation by a process of slow cooling and gravitative settling of crystals, and consequently they are found only in those regions which have suffered erosion for an enormous length of time.

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EXPLANATION OF PLATES

Plate I.

Fig. 1.—Mode of Occurrence of the dark coloured Anorthosite.

Fig. 2.—Inclusion of granular gabbro or norite showing deformed junction with the white Anorthosite.

Fig. 3.—Rock specimens showing the mode of formation of dark schlieren in the white rock by segregation.

Plate II.

Fig. 1.—[illegible] included mass of [illegible] gneiss in Anorthosite. The junction is irregular.

Fig. 2.—Black bands [illegible] in white Anorthosite.

Fig. 3.—Anorthosite [illegible] in [illegible] gneiss.

Fig. 4.—Thin band of Anorthosite in the gneissic basement.

Plate III.

Figs. 1 & 2.—Section of white Anorthosite showing the [illegible] out lines of the euhedral feldspar grains.

Figs. 3 & 4.—Shows [illegible] of the large [illegible] set in a granulitic base.

Plate IV.

Fig. 1.—Shows the stages in mechanical granulation of the feldspars.

Fig. 2.—Shows the close association of [illegible], hornblende and [illegible]. Note the white patch of leucoxene.

Fig. 3.—Section of white Anorthosite showing quartz.

Fig. 4.—Reaction rims of hypersthene, [illegible] and garnet round olivine.

Plate V.

Fig. 1.—Shows the formation of garnet by the reaction between pyroxene and feldspar.

Fig. 2.—Section of norite.

Fig. 3.—Shows the [illegible] of hornblende [illegible] derived from gabbro.

Fig 4—Junction between norite and Anorthosite showing the absence of sharp contact and interpenetration of the minerals of the adjacent fields.

Plate VI.

Fig 1—Section of granodiorite showing the mortarisation of the constituents and the presence of myrmekite with spherical [illegible].

Fig 2—Section of the grano-anorthosite hybrid showing the occurrence of labradorite felspars in granodiorite.

Fig 3—Perthite in Bengal gneiss.

Fig 4—Hornblende porphyroblast surrounded by granules of hornblende in the hornblende gneiss of Saltora.

Plate VII.

Fig 1 Section of granodiorite showing orthoclase quartz and oligoclase.

Fig 2—Section of granodiorite showing mortarisation of the constituents and development of myrmekite.

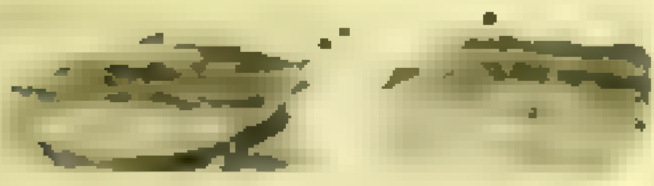


Plate II

Fig. 1

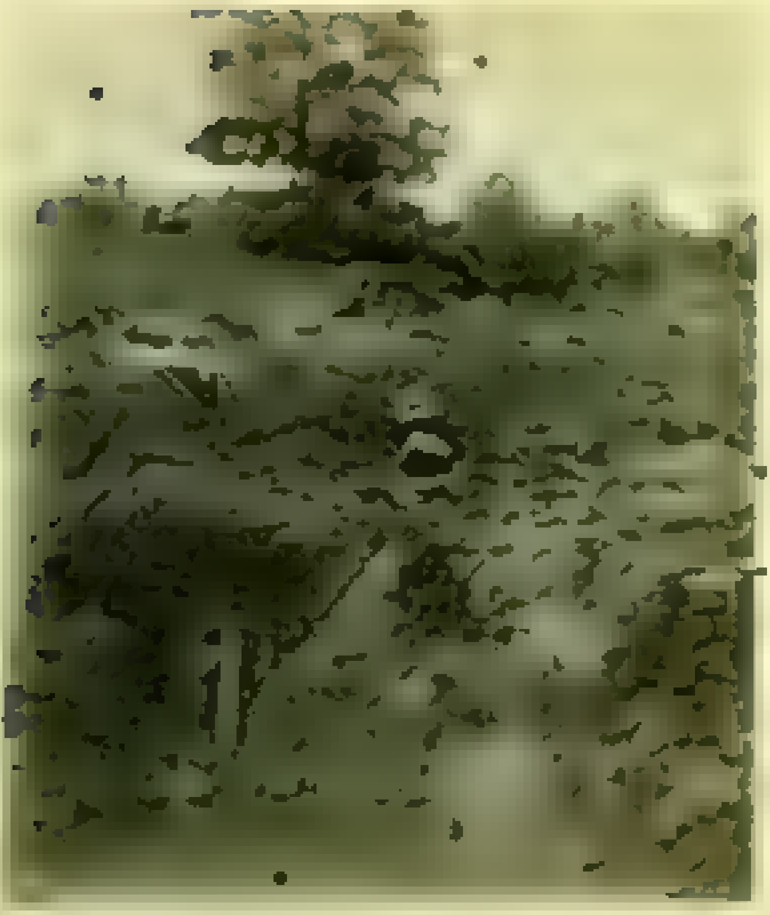
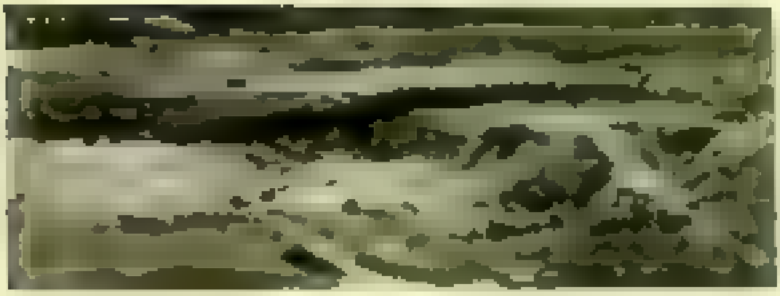


Fig. 2

PLATE II.



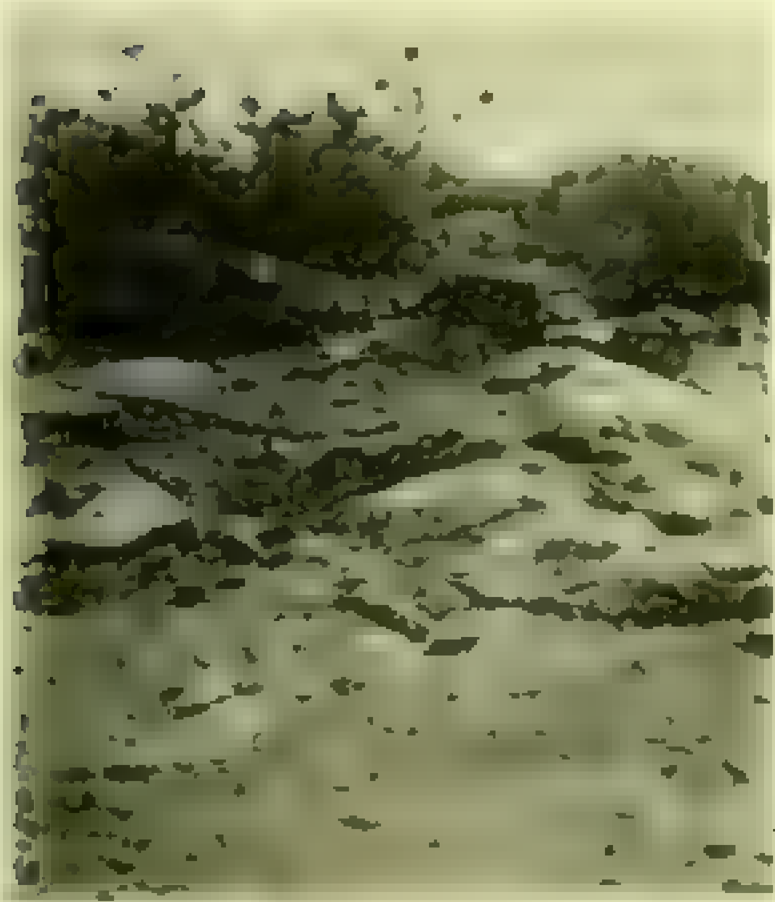


Plate III

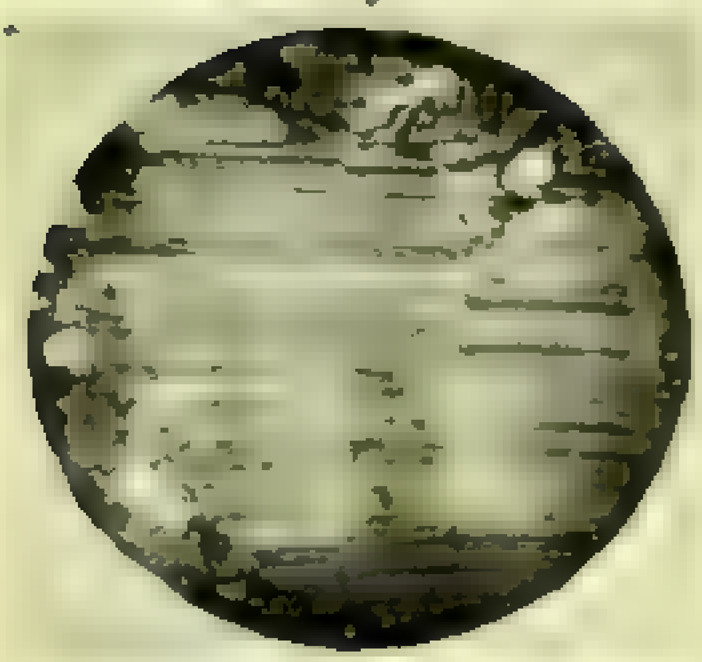


Fig. 1

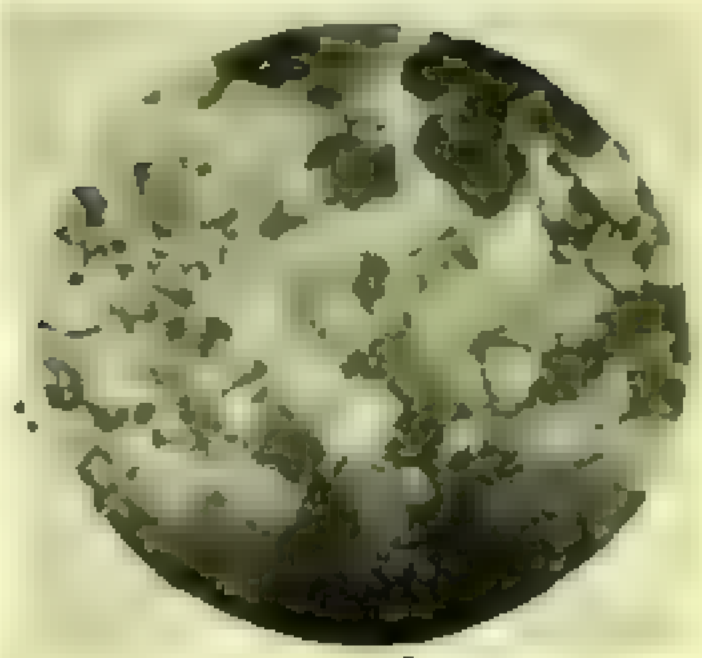


Fig. 2

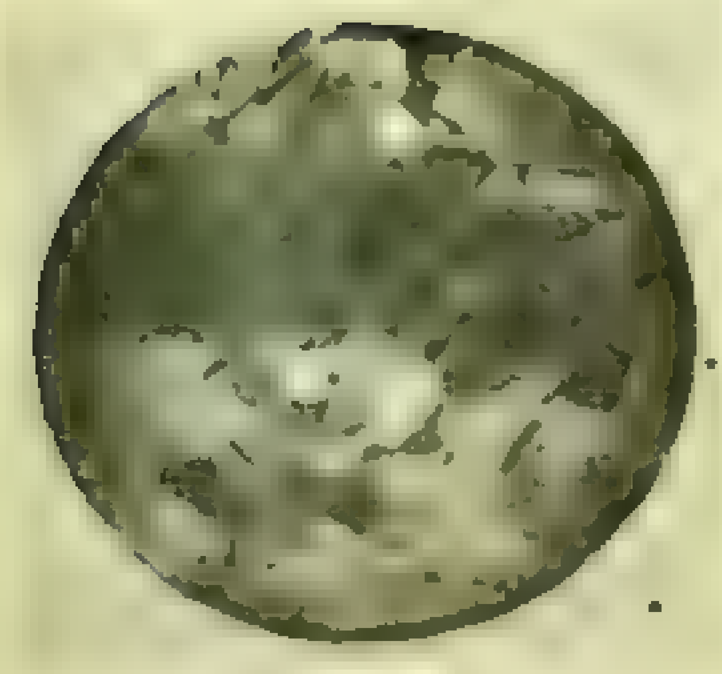


Fig. 3

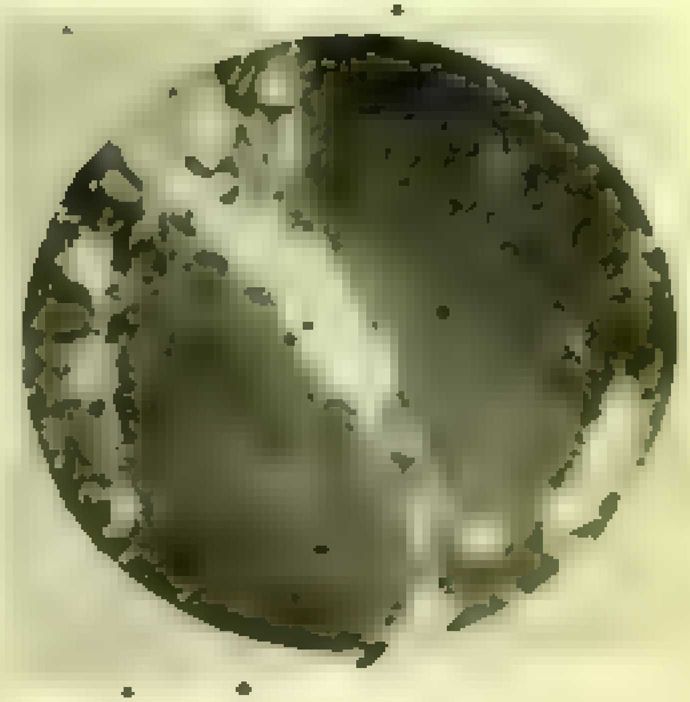


Fig. 4

PLATE IV.

FIG. 1.

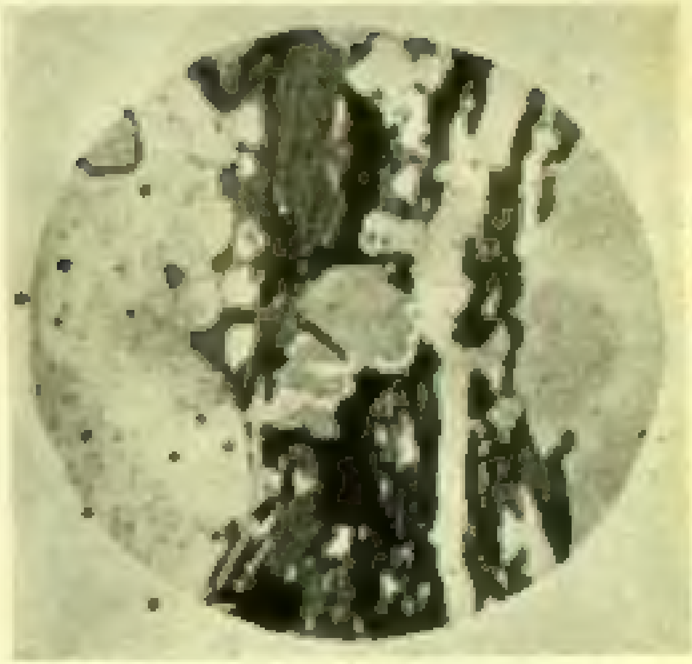


FIG. 2.

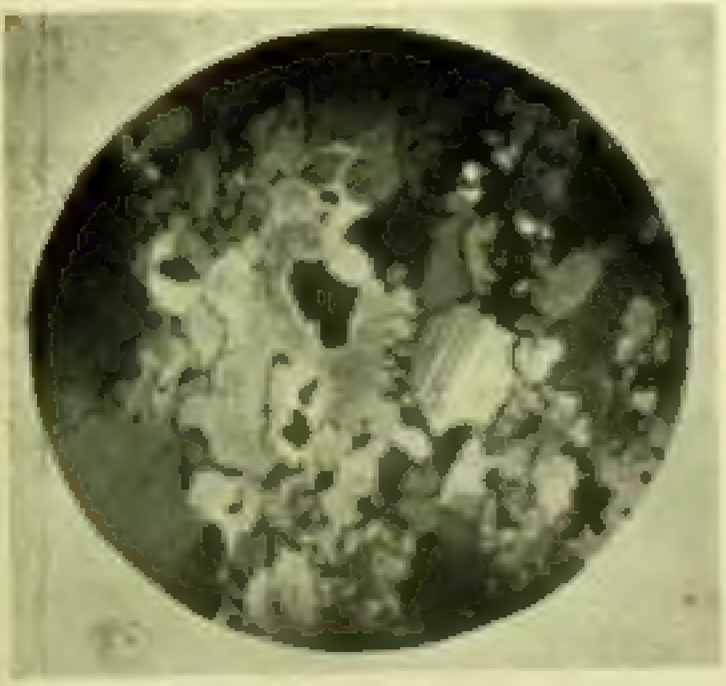


FIG. 3.

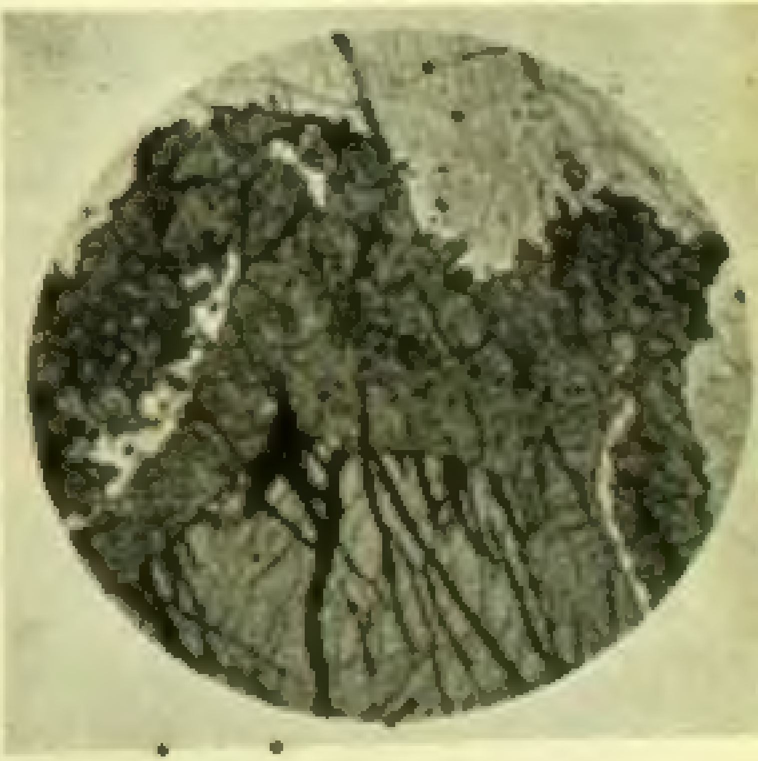


FIG. 4.

Plate V.

Fig. 1.

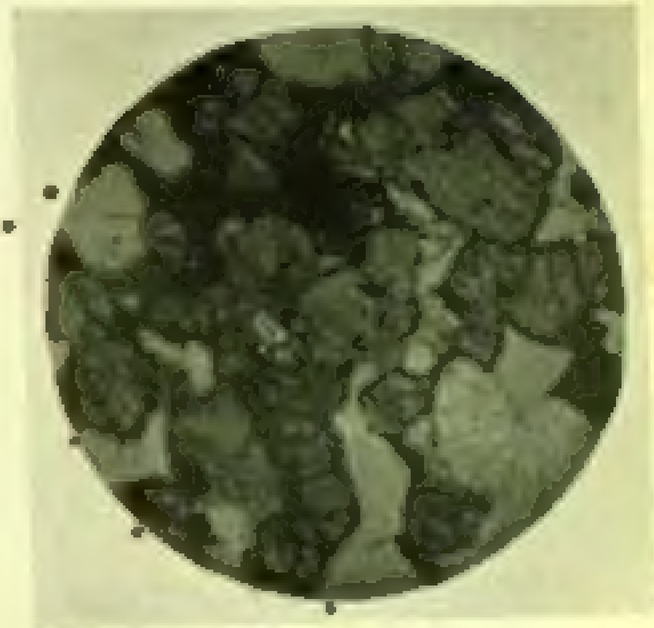


Fig. 2.

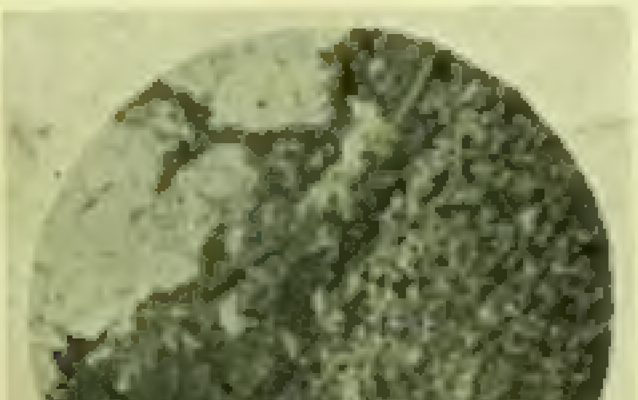


Fig. 3.

Fig. 4.

Plate VI.

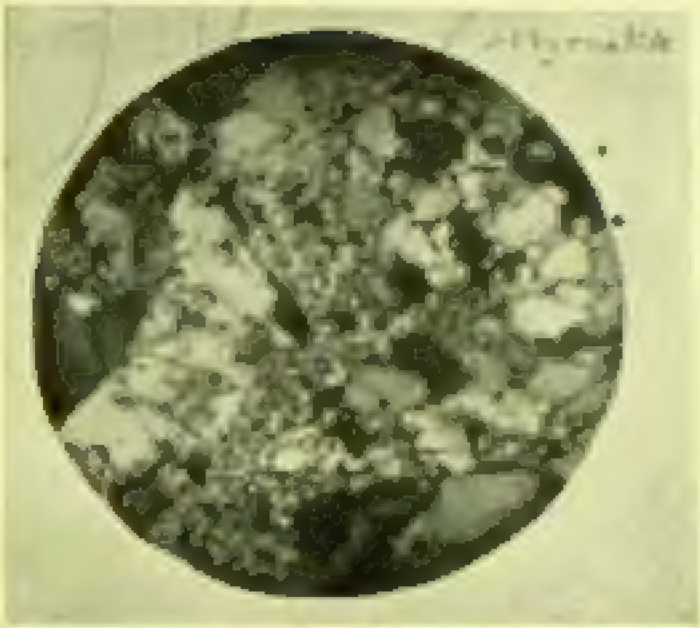


Fig. 1.

Fig. 2.

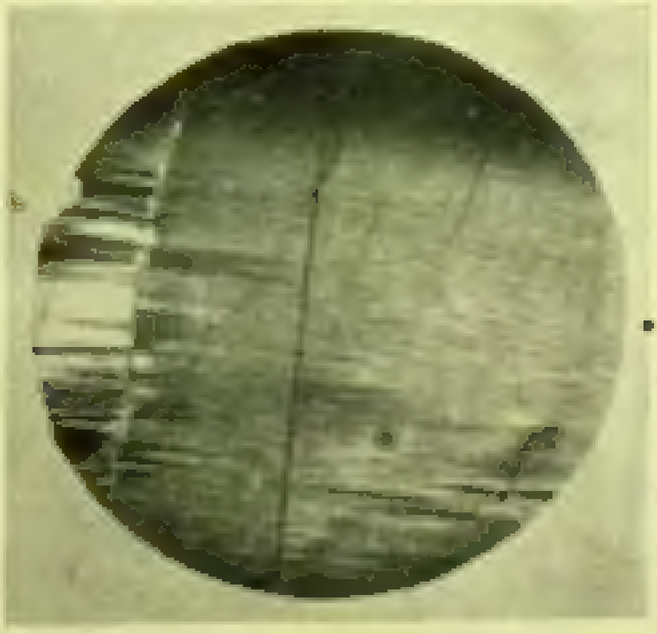


Fig. 3.

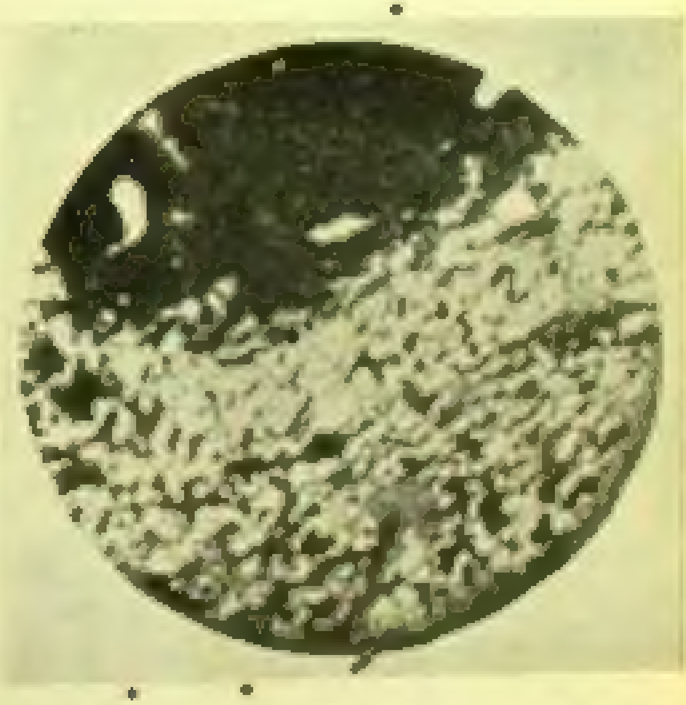


Fig. 4.

Plate VII.

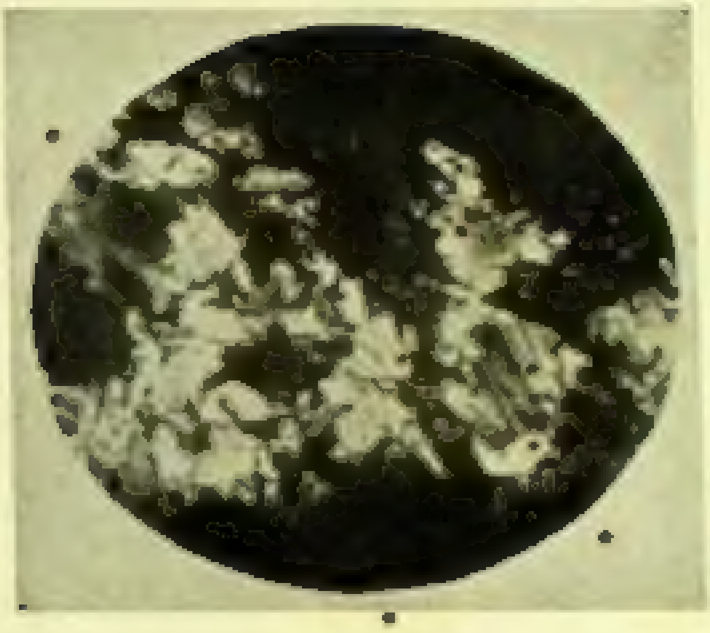


Fig. 1.

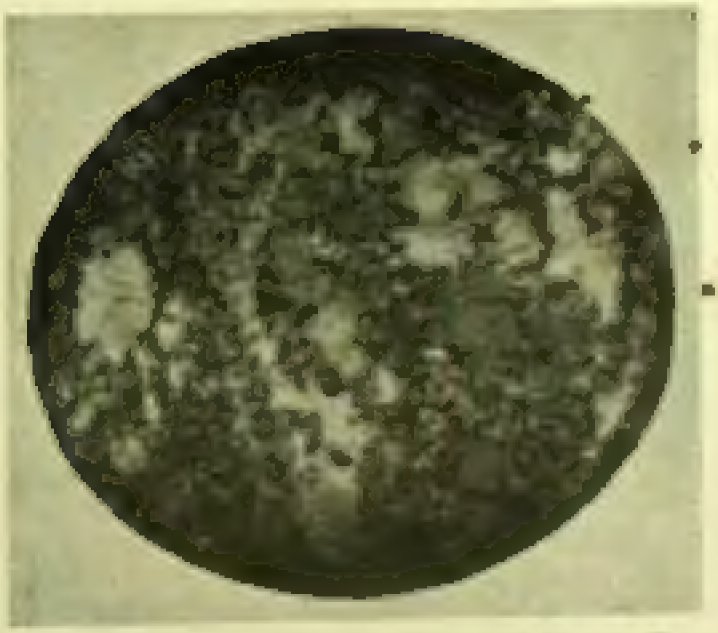


Fig. 2.